Strabismus measurements with novel video goggles

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Abstract: PURPOSE: To assess the validity of a novel, simplified, noninvasive test for strabismus using video goggles. DESIGN: Cross-sectional method comparison study in which the new test, the strabismus video goggles, is compared with the existing reference standard, the Hess screen test. PARTICIPANTS: We studied 41 adult and child patients aged 6 years with ocular misalignment owing to congenital or acquired paralytic or comitant strabismus and 17 healthy volunteers. METHODS: All participants were tested with binocular infrared video goggles with built-in laser target projection and liquid crystal display shutters for alternate occlusion of the eyes and the conventional Hess screen test. In both tests, ocular deviations were measured on a 9-point target grid located at 0±15° horizontal and vertical eccentricity. MAIN OUTCOME MEASURES: Horizontal and vertical ocular deviations at 9 different gaze positions of each eye were measured by the strabismus video goggles and the Hess screen test. Agreement was quantified as the intraclass correlation coefficient. Secondary outcomes were the utility of the goggles in patients with visual suppression and in children. RESULTS: There was good agreement between the strabismus video goggles and the Hess screen test in the measurements of horizontal and vertical deviation (intraclass correlation coefficient horizontal 0.83, 95% confidence interval [0.77, 0.88], vertical 0.76, 95% confidence interval [0.68, 0.82]). Both methods reproduced the characteristic strabismus patterns in the 9-point grid. In contrast to Hess screen testing, strabismus video goggle measurements were even possible in patients with comitant strabismus and visual suppression. CONCLUSIONS The new device is simple and is fast and accurate in measuring ocular deviations, and the results are closely correlated with those obtained using the conventional Hess screen test. It can even be used in patients with visual suppression who are not suitable for the Hess screen test. The device can be applied in children as young as 6 years of age.

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Strabismus Measurements with Novel Video Goggles

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Purpose: To assess the validity of a novel, simplified, noninvasive test for strabismus using video goggles.

Design: Cross-sectional method comparison study in which the new test, the strabismus video goggles, is compared with the existing reference standard, the Hess screen test.

Participants: We studied 41 adult and child patients aged ≥6 years with ocular misalignment owing to congenital or acquired paralytic or comitant strabismus and 17 healthy volunteers.

Methods: All participants were tested with binocular infrared video goggles with built-in laser target projection and liquid crystal display shutters for alternate occlusion of the eyes and the conventional Hess screen test. In both tests, ocular deviations were measured on a 9-point target grid located at 0±15° horizontal and vertical eccentricity.

Main Outcome Measures: Horizontal and vertical ocular deviations at 9 different gaze positions of each eye were measured by the strabismus video goggles and the Hess screen test. Agreement was quantified as the intraclass correlation coefficient. Secondary outcomes were the utility of the goggles in patients with visual suppression and in children.

Results: There was good agreement between the strabismus video goggles and the Hess screen test in the measurements of horizontal and vertical deviation (intraclass correlation coefficient horizontal 0.83, 95% confidence interval [0.77, 0.88], vertical 0.76, 95% confidence interval [0.68, 0.82]). Both methods reproduced the characteristic strabismus patterns in the 9-point grid. In contrast to Hess screen testing, strabismus video goggle measurements were even possible in patients with comitant strabismus and visual suppression.

Conclusions: The new device is simple and is fast and accurate in measuring ocular deviations, and the results are closely correlated with those obtained using the conventional Hess screen test. It can even be used in patients with visual suppression who are not suitable for the Hess screen test. The device can be applied in children as young as 6 years of age. *Ophthalmology 2017;■:1–8 © 2017 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).*

Supplementary material available at www.aaojournal.org.

Measuring ocular alignment and motility is essential for the diagnosis of strabismus and diplopia, for follow-up of patients with acquired or congenital strabismus, and for surgical treatment decision making. A method for mapping ocular deviation should be easy to perform for both the patient and the examiner and repeatable under the same conditions, and the results of successive examinations should be comparable to each other objectively.

The different techniques to assess ocular deviation can be divided into objective methods, as for example the cover test, and subjective methods, such as the Maddox rod test.[1] However, all need active cooperation of the patient. Probably the most commonly used method in clinical practice is the prism cover test (PCT). However, the PCT is performed manually and measurements depend on the examiner's attention and professional experience. Therefore the PCT is not absolutely reliable and may be inconsistent between repeated measurements by the same examiner or between several different examiners.[2] Furthermore, the examiner must observe the ocular movements during covering and uncovering of the eyes and may miss very small movements[3] that would be important in cases with subtle cranial nerve palsies.

Several variants of subjective screen tests are used clinically to measure and document ocular deviations.[4] The Hess[5–7] and Lancaster[8,9] screen tests both use red–green glasses to break binocular fusion. In the Hess test, the patient has to indicate targets on a red grid. While the red grid is only visible with one eye through the green glass by color subtraction, the red laser pointer can only be seen with the other eye through the red glass by color addition (Video 1, available at www.aaojournal.org). In the Lancaster test, the examiner projects a red light streak with a flashlight onto a grid (invisible to the patient through the glasses), which the patient has to match with a green flashlight. This allows the examiner to also estimate ocular torsion. The Harms tangent

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screen[10] is a similar but more cumbersome test that serves to quantify the horizontal, the vertical, and additionally the torsional components of ocular misalignment. In contrast to the Hess and Lancaster screen tests, for the Harms test the head rather than the eyes is rotated into 9 different positions to achieve eccentric gaze.

With good patient cooperation, all these tests are accurate, but they lack objectivity because the patient must indicate the position of the light shown on the screen. Furthermore, these tests cannot be performed accurately in patients with visual suppression or abnormal retinal correspondence. The tests also require additional personnel and take up to 20 minutes to complete. Computerized versions have been developed, but they still have the same patient requirements and limitations, and the results are not always fully comparable.[11,12]

An accurate and objective method using binocular dual search coils in a 3-field magnetic system has been developed.[13,14] However, this method is semi-invasive, as it involves placing silicone rings on the patient's cornea, and can only be used in cooperating patients. Therefore, it is not practical in clinical routine, is rather costly, and is time consuming.

For these reasons, there has been an ongoing search for alternative, objective, and noninvasive strabismus recording techniques. Several video-based infrared eye-tracking devices exist, but choices of commercially available video recording systems suitable for strabismus are scarce.[15,16] Most video recording systems are not tailored to clinical strabismus measurements, as they do not include all the components necessary for these measurements.

Therefore, we developed a pair of novel portable strabismus video goggles, which include a head-fixed laser target display and liquid crystal display (LCD) shutters for binocular dissociation. In the current study, we compared the performance of our new strabismus video goggles with the standard Hess screen test (Video 1, available at www.aaojournal.org).

Methods

Ethics

The study was approved by the ethics committee of the canton of Zurich (KEK-ZH-Nr. 2014-0481) and by SwissMedic (2014-MD-0028). The study adhered to the ethical standards laid down in the Declaration of Helsinki for research involving human subjects, and written informed consent was obtained from all participants or their parents. The study was registered at ClinicalTrials.gov (NCT02228070) and the study device was registered in the European database of medical devices (EUDAMED CIV-14-09-012767).

Subjects

Subjects were recruited between July 2015 and July 2016 from the Department of Ophthalmology at the University Hospital Zurich. Included were 41 patients and 17 healthy volunteers (total 58 subjects) aged 6 to 81 years (median, 37 years). The patients had various forms of ocular misalignment, such as congenital or acquired paralytic strabismus (4 third, 16 fourth, and 5 sixth nerve palsies), comitant strabismus (12 esotropia and 1 consecutive exotropia), and 3 various diagnoses (Miller Fisher syndrome, thyroid eye disease, meningioma with orbital apex syndrome). The 17 healthy volunteers did not have any known ocular misalignment or motility deficits. Exclusion criteria were noncooperating patients, patients unable to perform the standard tests (e.g., owing to hearing problems or other disabilities), uncorrected visual acuity of less than 0.05 (20/400) in either eye, anomalous retinal correspondence, eccentric fixation, extreme angles of strabismus (larger than 60 prism diopters), and severe limitation ($<15°$) of ocular movements. Three patients were unable to undergo Hess screen testing because of visual suppression but completed video-oculography. Three patients had to be excluded from the analysis for technical reasons.

Examination Procedure

All subjects underwent complete ocular examinations, visual acuity measurements, cover and alternate cover tests, alternate PCT, double Maddox test, and Lang stereoacuity test,[17] as well as Hess screen testing and video-oculography. All tests were performed by the same study team and were done under the same light conditions.

Hess Screen Test. A standard Hess screen test was used with a red grid printed onto a gray tangent screen, located at a distance of 0.5 m from the subject (Video 1, available at www.aaojournal.org).[5] Fixation targets on the 9-point grid were located at $0\pm15°$ horizontal and vertical eccentricity of a Hess coordinate system with non-nested, head-fixed horizontal and vertical rotation axes. During the test subjects were seated in front of the screen with the head on a chin rest and wore glasses with a red filter in front of one eye and a green filter in front of the other eye. The eye with the green filter sequentially fixated on the 9 different locations on the grid, which could not be seen by the eye with the red filter. The latter eye, however, guided the pointing of a red laser light by the patient, which could not be seen by the eye with the green filter. The red light was moved by the patient to the perceived points on the grid and the examiner noted the deviation on the grid of each point on a paper chart. The filters were then switched between the eyes and the procedure was repeated. The horizontal and vertical difference between the locations of the red light and the target positions on the red grid correspond to the phoria, the ocular misalignment in the absence of binocular fusion. The results on the paper charts were scanned and digitized using MATLAB software (MATLAB R2014b, 2014, The MathWorks Inc, Natick, MA).

Video-oculography. Binocular video goggles with a head-fixed target display were designed specifically for this study and built with rapid prototyping (Fig 1; Video 1, available at www.aaojournal.org).[18] Binocular eye position was recorded at 36 Hz with lightweight digital infrared video cameras (Firefly MV, Point Grey Research Inc, Vancouver, British Columbia, Canada). The images of the eye were deflected to the cameras with hot mirrors to provide an unobstructed view to the presented targets. The eyes were illuminated by infrared light-emitting diodes (LED) (TSUS502, Vishay Intertechnology, Malvern, PA), which were invisible to the subject to allow for recording even in complete darkness. The LED was run at 20 mA to keep infrared radiation far below exposure risk levels.[19] Binocular horizontal and vertical eye positions were calculated from the video images.[20] The area of the pupil was detected using image thresholding to estimate eye position based on the center of gravity of the pupil area.[21] Targets in a $0\pm15°$ 9-point grid were projected with a head-mounted class 1 mini-laser on a turret onto a screen at 0.5 m distance. The laser target was sufficiently bright to be visible by subjects with low uncorrected vision. The turret rotated horizontally, and different lasers mounted in the

Figure 1. Strabismus video goggles with a head-mounted laser for target display. The patient sequentially fixates laser targets on a 9-point grid while the eyes are alternately occluded and binocularly recorded. (**1**) Lightweight infrared cameras for eye-movement recording. For uniform illumination, each eye is illuminated with 4 infrared light-emitting diodes embedded into the goggles frame. (**2**) Hot mirror for reflection of the image to the camera. (**3**) Liquid crystal display shutter for occlusion of the eye to visible light but transparent for infrared light. (**4**) Laser turret for head-mounted target display. Binocular video signals are transmitted to the recording computer via 2 USB cables (not shown). Total weight of the prototype is ~100 g.

turret were used for the 3 target elevations. The eyes were alternately occluded with an LCD shutter. Even when closed for visible light, the shutters remained fully transparent to infrared light for uninterrupted binocular eye movement recording. Each LCD shutter occlusion was 2 seconds long and 3 cycles of alternate eye occlusion were performed at each gaze position. Horizontal and vertical eye position was determined as the median eye position during the last second of fixation. Because each eye fixated 9 positions of the 9-point target grid separately during the test, these eye position data could be used to calibrate the system,[20] so no separate calibration procedure was necessary. As the shutter changed 3 times for each fixation target, the median of those 3 fixation periods was used for further analysis. The measurement paradigm lasted 2 minutes. The recordings were done under normal lighting conditions in the examining room. To match the examination conditions with the Hess screen test, the subject was seated 0.5 m in front of a white screen with a head rest and chin fixation in place. The recording was done with custom LabVIEW software (National Instruments, Austin, TX). Further off-line analysis was performed using MATLAB software as described below.

Analysis of Results

Results of the strabismus video goggles and the Hess screen test were converted to degrees of eye rotation. For each patient and test, we calculated the horizontal deviation d_h and vertical deviation d_v (left eye − right eye) at each fixation point. Total deviation d_t was calculated as the Euclidian distance with the Pythagorean formula $\sqrt{d_h^2 + d_v^2}$.

Statistical Analysis

The intraclass correlation coefficient (ICC)[22] was used to assess the agreement of the strabismus video goggle measures with the Hess screen test. The analysis method[23] was implemented using a macro based on Proc Mixed in SAS software version 9.4 (SAS Institute Inc, Cary, NC). In this model, subjects were treated as random intercepts and the test (strabismus video goggles or Hess screen test) was treated as a fixed effect. In models assessing total deviation, fixed effects for vertical and for horizontal deviations were included as covariates. In addition, absolute levels of agreement between the strabismus video goggles and the Hess test were calculated as the mean difference, with 95% limits of agreement. For graphical analysis of the agreement, mean difference plots[24] and folded empirical cumulative distribution plots[25] were constructed.

Results

Patient Characteristics

We measured 58 subjects with our strabismus video goggles (Fig 1; Video 1, available at www.aaojournal.org), including 41 patients with congenital or acquired paralytic strabismus (4 third, 16 fourth, and 5 sixth nerve palsy; 3 various) or comitant strabismus (12 esotropia, 1 consecutive exotropia) and 17 normal subjects. The results were compared with the conventional Hess screen test and all subjects underwent a complete orthoptic and ophthalmologic examination.

Strabismus Video Goggle Recordings

Figure 2 illustrates the recording procedure with our strabismus video goggles in a typical patient with left fourth nerve palsy. While the laser target projected from the turret on the video goggles was displaced from one point to the next on the 9-point grid, the eyes were alternately occluded with LCD shutters (Fig 2A). In contrast to the Hess screen test, where the red−green glasses are only reversed once during the whole procedure, for recording with the video goggles occlusion was alternated at each target position, resulting in 3 fixation periods for each eye. Based on the binocular eye positions recorded during this alternate fixation (Fig 2B and C), median relative deviation of the covered eye from the target was calculated and displayed in the same format normally used for the Hess screen test (Fig 2D and E). The results acquired with the strabismus video goggles were similar to those of the traditional Hess screen test (Fig 2F and G), showing the typical pattern of a left fourth nerve palsy with increasing hyperdeviation of the affected left eye in right gaze (Fig 2D and F) and increasing hypodeviation of the healthy right eye in right gaze (Fig 2E and G).

Similarly, Figure 3 illustrates a second example, with a left partial third nerve palsy with primary hypodeviation and exodeviation of the affected left eye when covered (Fig 3A and C). Correspondingly, the covered healthy right eye showed secondary hyperdeviation and exodeviation (Fig 3B and D). Although the Hess screen test showed larger vertical deviations in upgaze, the typical pattern of a third nerve palsy with contraction of the grid and primary hypotropia and exotropia of the affected eye, as well as the consecutive expansion of the grid of the healthy eye, was clearly apparent in both tests.

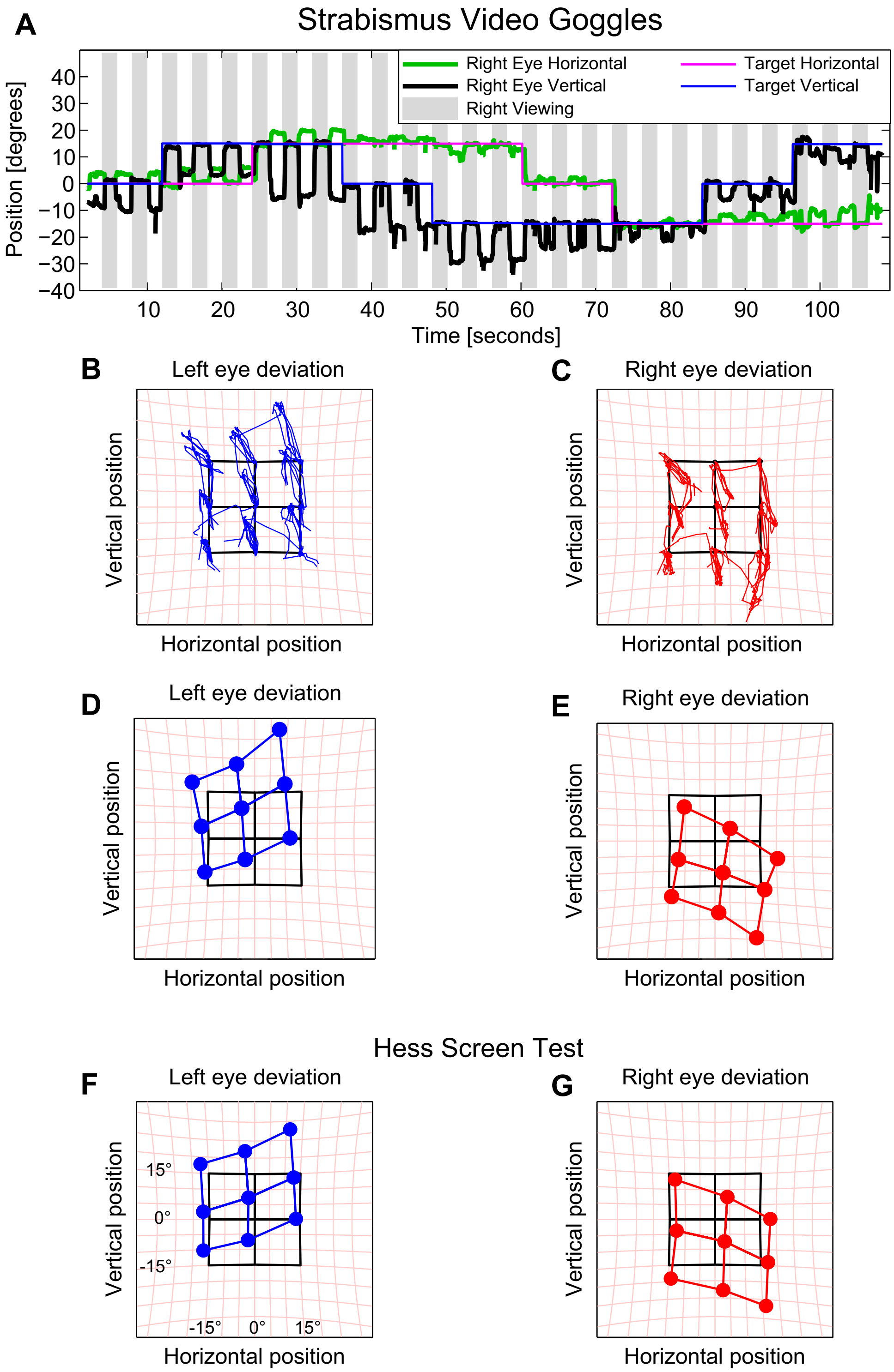

Figure 2. Left fourth nerve palsy measured with strabismus video goggles (**A**–**E**) compared with the conventional Hess screen test (**F**, **G**). **A**, Time series illustrate the recording procedure with the strabismus video goggles. While the laser target (horizontal: magenta; vertical: blue) is displaced from one point to the next on the 9-point grid, the right eye (horizontal: green; vertical: black) and the left eye (not shown) are alternately occluded with liquid crystal display shutters (gray grating). For each target position, occlusion is alternated every 2 seconds over 3 cycles. **B**, Left (blue) and **C**, right (red) eye-movement traces during alternate occlusion on a screen from the subject's perspective. From the eye positions of the covered eye, Hess screen graphs are assembled illustrating the deviation of the left (**D**) and right eye (**E**) in 9 different gaze directions. Both measurements are in close correspondence and show the typical pattern of a left fourth nerve palsy. The covered affected left eye (blue) shows increasing primary hyperdeviation with adduction (**D**, **F**), whereas the covered healthy right eye (red) shows increasing secondary hypodeviation with abduction. For both measurement methods, distance to the screen was 50 cm and laser targets were presented at ±15° horizontal and vertical eccentricities (black 9-point grid).

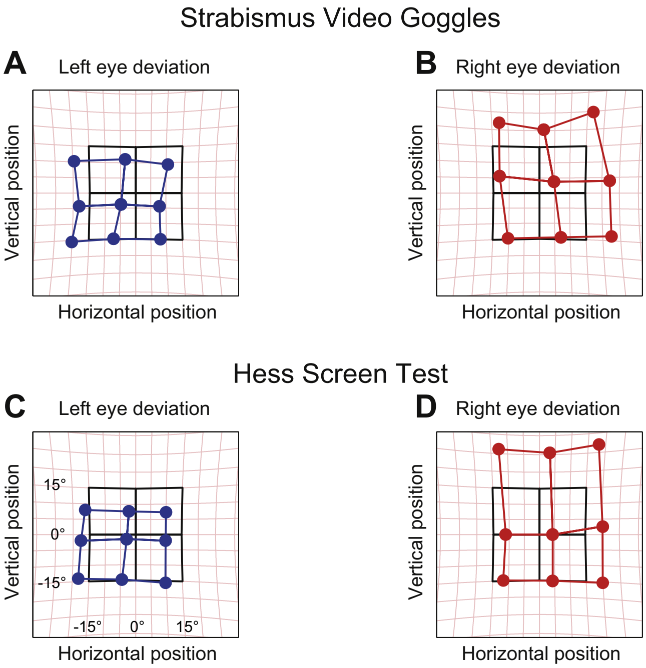

Figure 3. Partial left third nerve palsy measured with strabismus video goggles (**A**, **B**) compared with the conventional Hess screen test (**C**, **D**). Both measurements are in close correspondence and show the typical pattern of a third nerve palsy with contraction of the grid and primary hypodeviation and exodeviation of the affected left eye (**A**, **C**, blue). The covered healthy right eye (**B**, **D**, red) shows secondary hyperdeviation and exodeviation with expansion of the grid.

Comparison of the Strabismus Video Goggles with the Hess Screen Test

Figure 4 examines the correlation between the strabismus video goggles and the Hess screen test for the overall horizontal and vertical deviation between the left and right eyes. The ICC for all 9 horizontal deviations was 0.83, 95% confidence interval (CI) (0.77, 0.88); the ICC for the vertical deviations was 0.76, 95% CI (0.68, 0.82); and the ICC for the total deviation in all 9 gaze directions was 0.82, 95% CI (0.71, 0.89). The correlations between the 2 tests were also examined individually for each of the 9 fixation points (0±15° horizontal and vertical) (Fig S1, available online at www.aaojournal.org). ICC were similar in primary, secondary, and tertiary eye positions, indicating that the goggles performed equally well in different gaze directions.

Figure 4B, a mean-difference plot, was used to evaluate if the difference between the strabismus video goggles and the Hess screen test varied with the size of ocular deviation. Although the mean differences were close to zero for both directions, the 95% limits of agreement were larger for horizontal (mean −1.0° limits of agreement [−12.1°, +10.1°]) than vertical directions (−0.5° [−6.7°, +5.7°]).

For further evaluation of the differences, folded empirical distribution (mountain) plots for both the horizontal and vertical ranked differences were constructed (Fig 4C). The peaks of both horizontal and vertical distributions, representing the median, were close to 0°, indicating that the strabismus video goggles were unbiased relative to the Hess screen test. The vertical distribution was slightly narrower than the horizontal, indicating that the strabismus video goggles and Hess tests were in closer agreement for vertical deviations. To the contrary, the tails for the horizontal distribution were wider, suggesting a greater possibility of outliers or measurement errors for horizontal deviations.

Clinical Application

For the study, the strabismus video goggles were applied to a wide spectrum of strabismus patients, including children as young as 6 years of age. As it turned out, the strabismus video goggles were able to reliably quantify the ocular deviation even in patients with visual suppression, in whom conventional Hess screen testing was not possible. Figure 5 illustrates a patient with large consecutive exotropia after 3 previous strabismus surgeries for infantile esotropia, in whom visual suppression prevented the use of the Hess screen test. Nevertheless, the strabismus video goggles, which do not require simultaneous perception, measured comitant horizontal deviations of about 30° in this patient. The ease of use of the strabismus video goggles also facilitated follow-up examinations. Preoperative and postoperative measurements have been acquired in 4 patients, as exemplified in a patient with acquired sixth nerve palsy (Fig 6).

Discussion

We designed novel strabismus video goggles with built-in laser target projection and LCD shutters for automated alternate occlusion of the eyes (Fig 1; Video 1, available at www.aaojournal.org). The ocular deviation measurements with the device were closely comparable to the traditional Hess screen test across patients and healthy subjects, with an overall ICC of 0.82. Our novel goggles are quick and easy to use, can be applied in children as young as 6 years of age and possibly even younger, and can even be used in patients with visual suppression, who are not suitable for the Hess screen test.

The traditional Hess screen test has been rendering good service to strabismus experts for over a hundred years.[5,6] The test is simple, is reliable, and provides a paper chart for the medical records. However, in contrast to the cover test, which requires the patient only to fixate on a target, the Hess screen test is subjective and needs good patient cooperation. The method also requires simultaneous perception with both eyes to locate the target on the grid, rendering it unsuitable for patients with visual suppression. Therefore, we set out to develop new strabismus video goggles, which combine the principle of the subjective Hess screen test with the advantages of objective video measurements based on the alternate cover test with LCD shutters.

With a recording time of about 2 minutes, our video method is quick, is simple, and can be used in a clinical setup without a special screen. As the target projection is head-fixed, a distant white wall is sufficient for projection and a head rest is dispensable. Head-free recording also allows for Bielschowsky head-tilt testing for diagnosing patients with fourth nerve palsy.[14] Because the measurements are not examiner dependent, a trained technician can operate the goggles and collect the data for later evaluation by the treating physician. In patients who can look at all dots of the 9-point grid with each eye, the system is even self-calibrating, as the viewing eye is always fixating a defined gaze position, which can be used for calibration after recording. Another advantage of our goggles, compared with

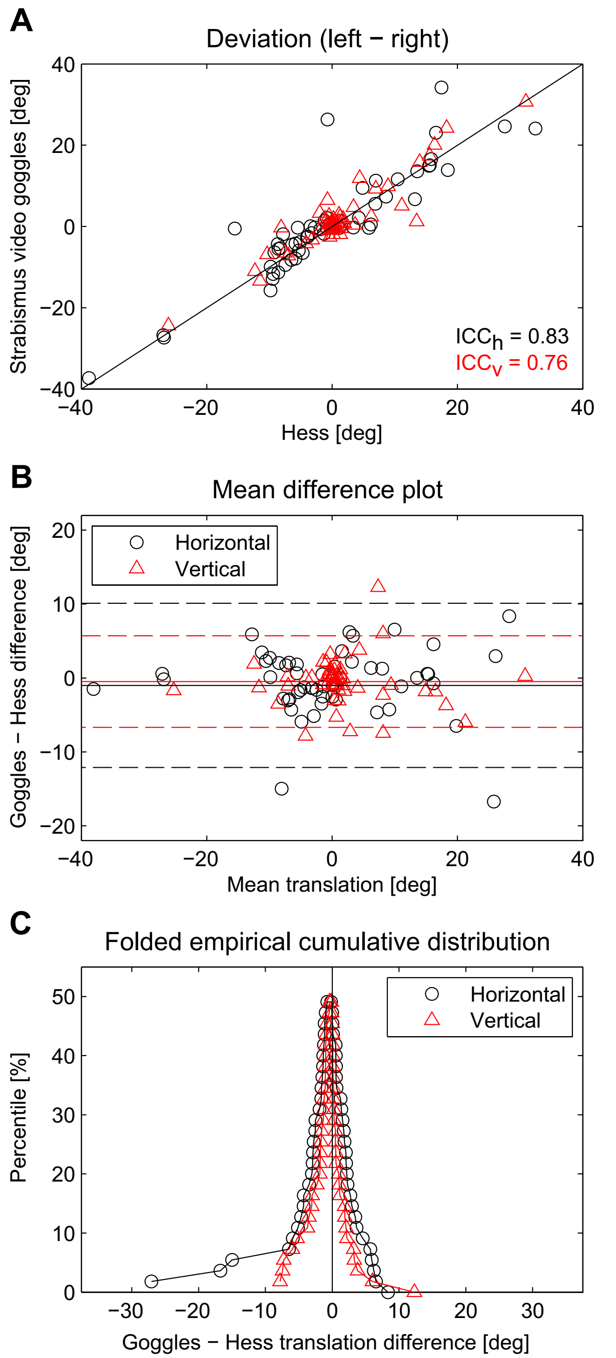

Figure 4. Global correlation between strabismus video goggles and Hess screen measurements. **A**, Correlation of the average deviation of all 9 fixation points between the 2 methods. **B**, Mean difference plots for assessment of the agreement between the strabismus video goggles and the Hess screen test. Means of both horizontal (−1.0°, solid black line) and vertical (−0.5°, solid red line) differences are located close to zero. The 95% limits of agreement are wider for horizontal deviations (dashed black line) compared with vertical deviations (dashed red line). **C**, Folded empirical cumulative distribution plots for illustration of the ranked differences between the 2 tests. The medians (peaks) of both horizontal (black) and vertical (red) differences are centered over zero, indicating no systematic bias between the 2 tests. The narrower vertical peak indicates slightly closer vertical than horizontal agreement, while the wider horizontal tails suggest greater possibility of outliers. $ICC_{(h/v)}$ = intraclass correlation coefficient (horizontal/vertical).

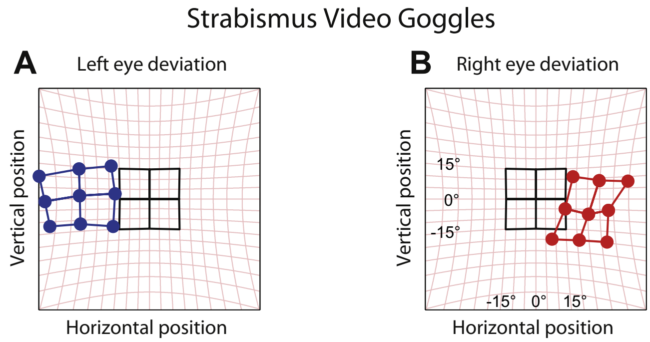

Figure 5. Example patient with large consecutive exotropia and visual suppression. Conventional Hess screen testing was not possible owing to visual suppression, but the strabismus video goggles are capable of measuring the large angles of exodeviation at different gaze positions. Whereas the Hess screen test requires simultaneous perception of the grid in one eye and the laser target in the other eye, the test paradigm of the strabismus video goggles with alternate occlusion does not need simultaneous binocular perception. The patient developed consecutive exotropia after 3 strabismus operations for infantile esotropia at ages 6, 8, and 44. **A**, Deviation of the covered left eye. **B**, deviation of the covered right eye.

previously developed video methods,[26,27] is that the movements of the covered eye can also be measured because the infrared cameras are capable of recording the covered eye through the closed LCD shutter, so that the deviation between the 2 eyes can be quantified directly.

Traditional screen tests to map ocular deviations, such as the Hess screen test,[5,6] the Lancaster red−green test,[8] or the Harms tangent screen test,[10,28] are time-proven measurement methods that can be used for diagnosis and follow-up of patients with strabismus.[1] However, they all require experienced examiners with sufficient knowledge of operating and recording the data correctly. The examiner must be alert to follow the subject's answers and mark them correctly on paper. In addition, these tests are time consuming and require special equipment and a large room with a blank wall for mounting the grid screens. However, eye movement measures with scleral search coils, the historical gold standard for oculography,[13−15] are semi-invasive, cumbersome, and only possible in specialized laboratories.

Patient cooperation is essential for the traditional screen tests, as patients need to understand the examiner's instructions so as to indicate the perceived position of the target. The use of the strabismus video goggles is very simple and straightforward, and after a brief explanation, children as young as 6 years of age completed the test accurately in our study. In contrast to the Hess screen test, we expect that in clinical practice the strabismus video goggles can readily be applied to cooperative children of even younger age. The ease of use of the goggles also facilitates follow-up examinations, for example before and after strabismus surgery (example patient, Figure 6).

Although small-angle strabismus can be measured with the Hess screen test, it often requires extra testing using a larger 0±30° grid in addition to the standard 0±15° grid to reveal the small ocular deviations.[1] With our goggles, small shifts can already be detected with the 0±15° laser grid, because they act as an automated alternate cover test. The

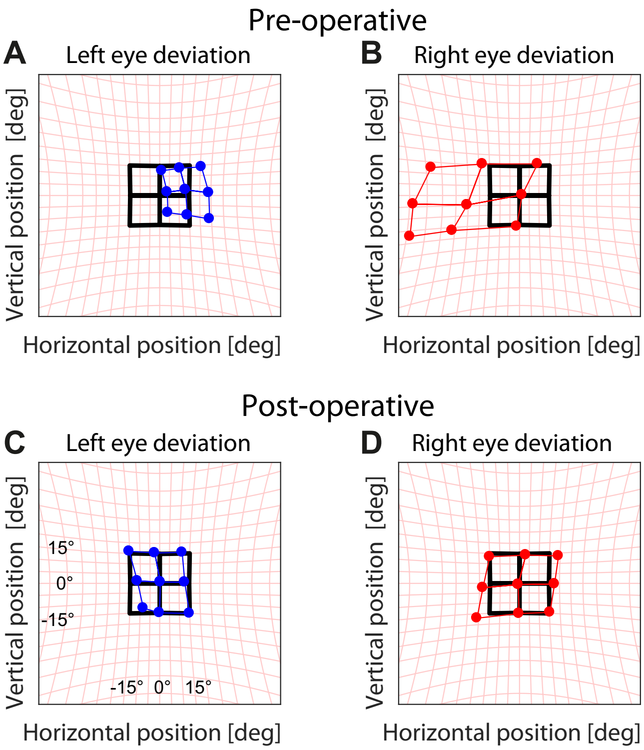

Figure 6. Preoperative and postoperative assessment of a patient with acquired left sixth nerve palsy. Preoperative measurements with the strabismus video goggles (**A**, **B**) illustrate a primary abduction deficit of the left eye with consecutive secondary adduction excess of the right eye. Three months after a combined resection of the right lateral rectus muscle and recession of the right medial rectus muscle, the strabismus video goggles (**C**, **D**) document a favorable postoperative outcome. Note that the patient already underwent strabismus surgery 10 years before the current evaluation with combined resection of the left lateral rectus muscle and recession of the left medial rectus muscle, which explains why surgery was performed on the nonparetic eye.

LCD shutters alternately cover and uncover both eyes, so that any latent component of the strabismus can be measured with the binocular infrared cameras through the shutters.

Another advantage of the strabismus video goggles is the possibility to measure even subjects with visual suppression, as for example congenital comitant strabismus (example patient, Fig 5).[29] These patients are not able to perform any traditional screen tests, which require simultaneous perception with both eyes to compare the dissociated images. In contrast, the strabismus video goggles do not require binocular perception, as they are working based on the principle of the alternate cover test. Likewise, the strabismus video goggles may provide useful objective information about the strabismus pattern even in patients with abnormal retinal correspondence.

One of the technical limitations of our newly developed prototype goggles is that they have been designed for an average-size head. Consequently, they did not fit all patients equally well, so that some targets have occasionally been obscured by the goggles frame, the video cameras, or the mounts of the hot mirrors. Nevertheless, they can be fitted comfortably to children. The current goggles prototype is not equipped to correct for refractive errors, as it is technically very demanding to fit trial lenses into the optical path of the system without compromising the field of view. Alternatively, recording with contact lenses does not usually pose a problem. In any case, the uncorrected visual acuity requirements for the test are low, as the patient only needs to track a bright laser target. Nevertheless, we excluded patients with an uncorrected visual acuity lower than 0.05 (20/400) for our study. In addition, the LCD shutters of our prototype did not always block vision completely at acute angles of incidence in corner eye positions, so that sometimes a shadow image of the laser target was perceived by the occluded eye. Nevertheless, the function principle of the goggles could be proven, so that these technical shortcomings can be overcome with future hardware iterations.

Video eye-tracking systems usually perform better near straight-ahead gaze, so we anticipated that the corner positions of the target grid would show the greatest differences between the Hess screen and the strabismus video goggles. To our surprise, the goggles performed equally well at all gaze directions, as documented by the similar intraclass correlation coefficients at all 9 target positions. Like the Hess screen test, the strabismus video goggles are limited in patients with severe paralytic strabismus. In these cases, calibration as well as measurements will be hampered if the affected eye cannot reach all 9 targets. Currently, the software analyzes only horizontal and vertical deviations, and ocular cyclotorsion has not been implemented yet. Methods for measuring ocular torsion have already been developed some years ago.[30,31] With the advent of fast image processing techniques, the implementation of algorithms for measuring cyclotorsion will certainly be possible in future software versions.

In summary, we developed a quick, easy, and reliable method for automated measurements of ocular deviation. The simple application of the strabismus video goggles allows clinicians to assess and diagnose patients with strabismus and follow their clinical course, as for example after strabismus surgery. The goggles can even be used in patients with visual suppression, as well as in children as young as 6 years of age. In this study, we successfully validated the strabismus video goggles against the Hess screen test in strabismus patients and healthy volunteers. With further refinement of the hardware and software, the strabismus video goggles will, we hope, soon be ready for daily clinical practice.

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Abbreviations and Acronyms:

CI = confidence interval; **ICC** = intraclass correlation coefficient; **LCD** = liquid crystal display; **LED** = light-emitting diode; **PCT** = prism cover test.

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